Jet production in diffractive processes at HERA

21-27 Jul 2005
Lisboa, Portugal

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Kinematics in diffraction

- $Q^2$: negative squared mass of photon
- $W$: virtual photon-proton CMS energy
- $M_X$: mass of hadronic system $X$
- $x_{\text{IP}}$: proton momentum fraction of the colorless exchange: Pomeron (IP)
- $\beta$: longitudinal momentum fraction of the exchange carried by the struck quark
Event topology in diffraction at HERA

- Diffractive exchange: exchanging states with vacuum quantum number
  - Colorless exchange
  - Producing large rapidity gap (LRG)

Diffractive scattering

Non-diffractive scattering
Kinematics in diffractive dijet

Dijet events can reconstruct the parton momentum from jets

\[ z_{\text{IP}}^{\text{jets}} = z_{\text{IP}}^{\text{obs}} = \frac{Q^2 + M_{12}^2}{Q^2 + M_X^2} \]

\[ z_{\text{IP}} : \text{Longitudinal momentum fraction of the parton for Pomerion related to the exchange for the hard interaction} \]

\[ x_{\gamma}^{\text{jets}} = x_{\gamma}^{\text{obs}} = \frac{\sum_{\text{jets}} E - p_z}{\sum_{\text{hadrons}} E - p_z} \]

\[ x_{\gamma} : \text{Longitudinal momentum fraction of the parton for photon related to the exchange for the hard interaction} \]

What is DIS or Photoproduction (PHP) ?
- DIS: \( Q^2 >> 0 \), mostly Direct
- PHP: \( Q^2 \sim 0 \), Direct + Resolved
Diffractive Parton Density Function (DPDF)

- **Diffractive PDF:**
  - like the normal PDF, but under the condition that a diffractive exchange is involved.
  - Reasonable description of inclusive diffractive measurements
    (See talk given by L. Schoeffel)

- **Gluons** from scaling violation
  - Large uncertainties

- **Example:** H1 2002 fit:
  - Gluon density is larger than quarks (~75 %)
  - Gluon uncertainties is large at high $z$.
  - Need to constrain the gluon with the other process
Diffractive PDFs and factorization

- Hard scattering for non-diffractive process:
  QCD factorization holds for jet production

- Assuming that this can be applied also in diffraction:
  - Cross section: convolution of matrix element and diffractive parton density
    \[ \sigma_{\text{dijets}}(\gamma^* p \rightarrow X p) = \sum_{i=q,g} \sigma_{\gamma i \rightarrow ij} \otimes f_i(z_{\text{IP}}) \]
  - Diffractive dijet events can reconstruct \( z_{\text{IP}} \)
    - \( z_{\text{IP}} \): Longitudinal momentum of the parton to hard scattering

- Dijet process: mainly from BGF (Boson-gluon-fusion) diagram
  \( \rightarrow \) Dijet is sensitive to diffractive gluon density
Factorization breaking between $ep$ and $pp$?

- CDF result in $pp$ collisions at Tevatron is factor $\sim 3-10$ lower than QCD fit using HERA diffractive PDFs.
- Why DPDFs from HERA do not work?

Suppression in diffractive dijet at HERA?

- Theoretically expected, explanation next
Jets in Photoproduction (PHP) at HERA

- Jets in Photoproduction (PHP):
  thought to be an ideal testing ground for rescattering

Large (resolved): hadron-like

\[ x_\gamma < 1 \]

No photon remnant

Secondary interaction filling rapidity gap

Suppressed

Small (direct): point-like

\[ x_\gamma \sim 1 \]

No photon remnant

Dijet in PHP will be suppressed

Prediction from Kaidalov et al.:
Suppression factor for resolved photoproduction \( R = 0.34 \)

\( \Rightarrow \) PHP result on the next slide
Dijet in PHP: shape comparison with LO MC

- Shape of cross section is well described by MC normalised to data.
  - MC does not include suppression of the resolved PHP contribution.
- Data / MC is flat in $x_\gamma$: No sign of resolved suppression
  - Some excess at highest $z_{IP}$: sensitivity to diffractive PDFs

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Suppression of PHP: Comparison with NLO

- NLO suppose to give stable prediction in normalisation
  - Comparison of absolute cross sections
  - Scale uncertainty in band

Result:
- Data/NLO(R=1) is flat in $x_\gamma$
  - Consistent with LO+PS
- But…
  - Data is lower than NLO(R=1) by ~0.6
- NLO(R=0.34) describes data in shape and normalization.
  ➔ Suppression of both direct and resolved

Prediction from Kaidalov et al.:
- No resolved suppression by R=1
- Resolved suppression by R=0.34

ZEUS
Suppression of PHP: Comparison with NLO

Like seen in $x_\gamma$ distribution
- Normalization factor in PHP is $\sim 0.5$.
- Shape of NLO in PHP describe data.

Look more in detail…
→ See next slide
Double differential cross sections for PHP

Data / NLO is approximately flat.

Data for both direct enriched and resolved enriched

- Data for both $x_γ > 0.75$ (direct) and $x_γ < 0.75$ (resolved): suppressed by ~0.6
- Both direct and resolved are well described in shape, but the magnitude of the cross sections is suppressed, assuming that H1 2002 fit is correct.

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Dijet in DIS: Comparison with LO MC

- Is the factorization breaking in diffractive dijets?
  - Check DIS events
  - Presence of hard scale ($Q^2$) should suppress rescattering.

- Both H1 and ZEUS has measured dijet cross sections
  - ZEUS: Proton dissociation ($16 \pm 4\%$) was subtracted.
  - H1: No subtraction of proton dissociation

- Comparison with LO MC:
  Shape is well described by LO+PS MCs (RAPGAP, SATRAP)
  (normalized to data).

Kinematic range
  - $5 < Q^2 < 100 \text{ GeV}^2$, $100 < W < 250 \text{ GeV}$
  - $x_{IP} < 0.03$
  - $N^*_{\text{jet}} \geq 2$, $E^*_{T,1\text{jet}} > 5 \text{ GeV}$, $E^*_{T,2\text{jet}} > 4 \text{ GeV}$
  - $-3.5 < \eta^*_{\text{jet}} < 0$
Dijet in DIS: Comparison with LO MC

- LO MC (dir.+res.) describe shape of cross section well.
- LO MC (dir. only) does not describe shape of cross section for $x_\gamma$

> Contribution of resolved process in diffractive DIS
Dijet in DIS: Comparison with NLO prediction

- **Kinematic range:**
  - $165 < W < 242$ GeV
  - $N_{\text{jet}}^* \geq 2$, $E_{T,*}^{\text{jet}\,1} > 5$ GeV, $E_{T,*}^{\text{jet}\,2} > 4$ GeV
  - DIS: $4 < Q^2 < 80$ GeV$^2$, $-3 < \eta_{\text{jet}}^* < 0$
  - $x_{IP} < 0.03$

- **Good agreement with NLO using H1 2002 fit PDFs**

  - **Factorization holds in dijet events, assuming DPDFs (H1 2002 fit) is correct.**
Dijet in DIS: Comparison with NLO prediction

- Comparison of both NLO with H1 2002 fit and ZEUS-LPS fit DPDFs
- ZEUS-LPS fit: to $F_2^D$ measured using ZEUS leading-proton spectrometer (LPS) and charm cross sections $F_2^{charm}$
- Scale uncertainty (band) by $0.5 \ E_{T,\text{jet1}}^* < \mu_r < 2 \ E_{T,\text{jet1}}^*$ → ~20% uncertainty
- NLO prediction with both DPDFs describe data in normalization
  ➔ Factorization holds if we assume these DPDFs are correct.
Uncertainty in diffractive PDFs

- New PDF fit recently available: GLP fit using the fit to the ZEUS $F_2^D$ data (using $M_x$ method): presented in HERA-LHC Workshop
- H1 2002 fit: to H1 $F_2^D$ data
- ZEUS-LPS fit: to $F_2^D$ by LPS and $F_2^{charm}$
- Quark density similar
- **Gluon density largely different at high $z$** ($=\text{Longitudinal momentum of parton}$)
- GLP fit for $M_x$ data is below H1/LPS at high $z$

→ Comparison of dijet cross section to NLO prediction using these fits
Comparison to NLO with various DPDFs (1)

- NLO prediction with ZEUS-LPS fit and H1 2002 fit DPDFs describe data in normalization.

- NLO prediction with GLP is below data.

⇒ DPDFs uncertainties
- Poorly constrained gluon density
Comparison to NLO with various DPDFs (2)

- NLO prediction with GLP is below data.
  - Difference in the shape and normalization on the diffractive gluon density.

- Difference between 3 sets of NLO prediction
  - Uncertainty in DPDFs

- This data would help understanding the partonic structure of the diffractive exchange.
Kinematic range as common as possible:
- $165 < W < 242$ GeV
- $N_{jet}^* \geq 2$, $E_{T,jet1}^* > 5$ GeV, $E_{T,jet2}^* > 4$ GeV
- DIS: $4 < Q^2 < 80$ GeV$^2$, $-3 < \eta_{jet}^* < 0$
- PHP: $Q^2 < 0.01$ GeV$^2$, $-1 < \eta_{jet_{lab}} < 2$
- $x_{IP} < 0.03$

Cross sections are compared through the ratio to NLO using the same DPDFs (H1 2002 fit)

Reducing the uncertainty in diffractive PDFs when comparing DIS and PHP cross sections. PHP cross section is suppressed by 0.5 w.r.t. DIS.
Conclusion

- Dijet cross sections are measured in both photoproduction and DIS.
- Cross sections are compared with NLO calculations with diffractive PDFs extracted from DGLAP QCD fit to HERA $F_2^D$ measurements.
- Photoproduction cross sections are by 0.5-0.6 below NLO using DPDFs, which describe DIS data (H1 2002 fit).
  - Factorization breaks in photoproduction if the assumed DPDFs are correct.
- NLO prediction with various DPDFs extracted from HERA $F_2^D$ shows large variation in dijet cross section, reflecting large uncertainty in DPDFs.
- NLO prediction with one set of DPDFs cannot simultaneously describe photoproduction and DIS dijet data.
- Both photoproduction and DIS dijet give constraint on the model of the partonic structure of the diffractive exchange, e.g. DPDFs.